Dekati Ltd Application Note

ELPI IN AUTOMOTIVE APPLICATIONS

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Introduction

ELPI™ (Electrical Low Pressure Impactor) measures particle size distribution and concentration in real-time. The operation principle is based on particle charging, size classification in an inertial low-pressure impactor, and current measurement with a sensitive multi-channel electrometer.

One of ELPI's main applications is automotive/engine exhaust measurement. The instrument can be used to measure emissions from engines that run on diesel, gasoline, different bio-fuels etc. ELPI™ provides real time information on the particle size distribution and concentration making it a useful tool especially in measuring particle emissions during different standard drive cycles (e.g. FTP, ECE-EUDC). Figure 1 presents an example of data from ELPI™ during the EUDC driving cycle.

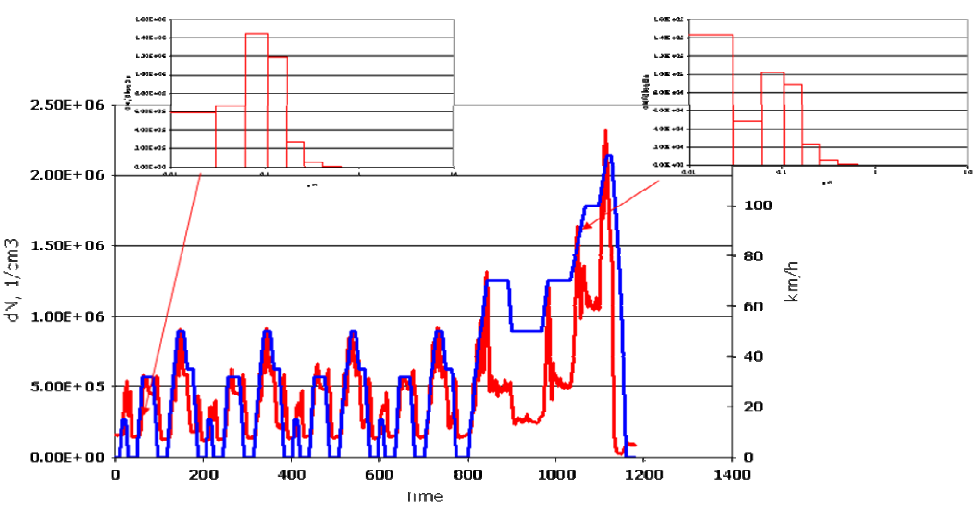

Figure 1. Example of ELPI™ data during a transient drive cycle.

ELPI^{TM} configuration

ELPI^{TM}s are available with two flow rates; 10 lpm and 30 lpm. The ELPI^{TM} configuration that is recommended to be used in exhaust measurements is a 10 lpm ELPI^{TM} (ELPI-01) with filter stage (ELA-650). The lower flow rate of 10 lpm makes cleaning intervals longer, and filter stage enables detection of the nucleation mode often present in exhaust measurements (7-30 nm), the standard ELPI^{TM} measurement range being 30 nm – 10 µm.

Few additional accessories can be used with ELPI^{TM} in exhaust measurements. The following accessories are not necessary but often useful in this application.

Aluminium foils with grease

The detection of particles in ELPI^{TM} is based on the measurement of electrical current. The particles hit the collection plates and the charge that they carry is detected with the electrometers. It is recommended to use greased aluminium foils on the collection plates. The foils (CF-300) protect the collection plates from fouling, and the plates don't need to be cleaned after each measurement but changing the foils is sufficient. In addition, greasing of the foils prevents bouncing of the particles, which may distort the detected particle size distribution. If chemical analysis of the particles is wanted, then polycarbonate (IPR-200) foils are recommended.

Dekati provides the grease in two forms. The grease is Apiezon-L vacuum grease, which is pure enough for chemical analysis. The standard grease (AG-10) is dissolved in a solvent after which it is applied on the aluminium foils with e.g. fine brush. Another option is the Apiezon-L grease in spray form (DS-515), which makes the greasing a bit faster. A stencil (DS-125) is needed for covering the edges of the foils during spraying.

Sintered collection plates

Standard ELPI^{TM} collection plates are stainless steel, and aluminium or polycarbonate foils should be used on them. The recommended maximum load of particles per one impactor stage is 1 mg. This value can vary depending on the particle type.

Sintered collection plates (IA-211) are used to make longer measurements without the need to clean the impactor. With sintered collection plates about 10 times more particles can be collected on one impactor stage making the cleaning interval of the collection plates longer and thus enabling longer measurement periods. Chemical analysis cannot be performed on the sintered collection plates, nor can gravimetric analysis be made. More information on the sintered collection plates can be found in the Dekati Ltd. technical note: Sintered collection plates.

ELPIVOLT External Data Logging Electronics

ELPIVOLT module enables saving three external signals into the ELPI^{TM} data file. Each channel in the module can measure voltages (±5 V or ±10 V DC), current loop signals (0-20 mA range) or temperatures with a K-type thermocouple. The module can be used e.g. to save dilution ratio from trace gas measurement in real-time into the ELPI^{TM} data file.

Sampling

The selection of the correct sampling system is extremely important especially in vehicle exhaust measurements. With a properly designed sampling system, particle losses and sample transformations can be minimised during sample transport, dilution and cooling. Dekati provides state-of-the- art solutions for this and the available options are presented below.

Tailpipe sampling

If the sample is taken out directly from the tailpipe, three options are available; Dekati® Double Diluter, Dekati® Engine Exhaust Diluter (DEED) and Dekati® Fine Particle Sampler.

Dekati® Double Diluter

Dekati® Double Diluter is a two-stage dilution system with a constant dilution ratio in stabile conditions. The system consists of two Dekati® ejector type diluters (DI-2000), and accessories for heating the first diluter (DI-2001 (110V), DI-2003 (230V)). More detailed information on the Dekati® Double Diluter setup can be found in the Dekati technical note Dekati® ejector diluter in exhaust measurements.

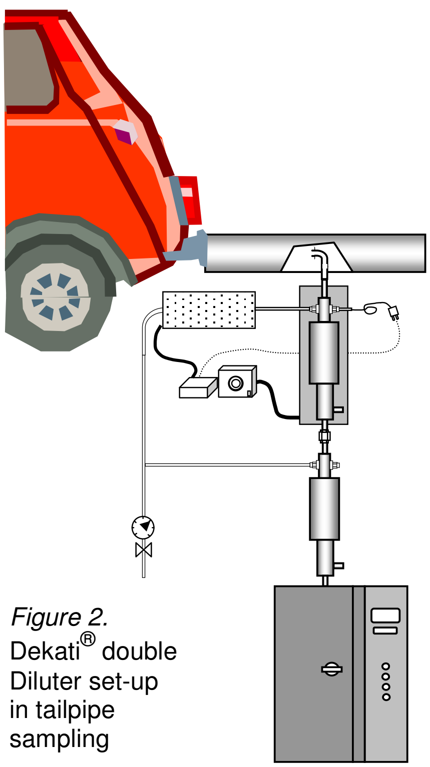

Figure 2.
Dekati® double Diluter set-up in tailpipe sampling

Figure 2 presents the Dekati® Double Diluter set-up when sampling directly from the vehicle tailpipe. The sample is taken out of the tailpipe into the first diluter with isokinetic sampling and heated sampling line. Also the first diluter including the dilution air for the first diluter is heated up to the temperature of the exhaust (max 400 °C). This way the thermophoretic losses can be minimised, and the vapour pressure of volatile compounds can be decreased in the first dilution stage to minimise nucleation of the VOCs (Volatile organic compounds).

The second dilution stage is in room temperature; the sample temperature is decreased to a suitable range for ELPI™, and the particle concentration is further decreased making the cleaning intervals of the ELPI™ impactor longer. More information on the Dekati® Double Diluter can be found in Dekati Ltd Technical note: Dekati® ejector diluter in exhaust measurements.

All in all, the Dekati® double diluter is an easy-to-operate system for exhaust emission measurements in stabile conditions with a constant dilution ratio. When driving transient cycles, it is recommended to monitor the dilution ratio with a trace gas measurement (e.g. CO_2), or use the Dekati® Fine Particle Sampler.

Dekati® Engine Exhaust Diluter (DEED)

Dekati® Engine Exhaust Diluter is a sample conditioning system specially designed for PMP measurements. The system fulfills all requirement of the upcoming PMP legislation and its structure is similar to that of Dekati® Double Diluter; the sample is diluted in two Dekati® ejector diluters with the first dilution stage heated. In addition to the two-stage diluter, the DEED incorporates a PMP specified evaporation chamber. An optional third dilution stage is also included in cases where higher dilution ratio is needed. All the components are placed in a single, compact housing for easy-to-use operation. The operating principle and photo of the DEED are presented in Figure 3.

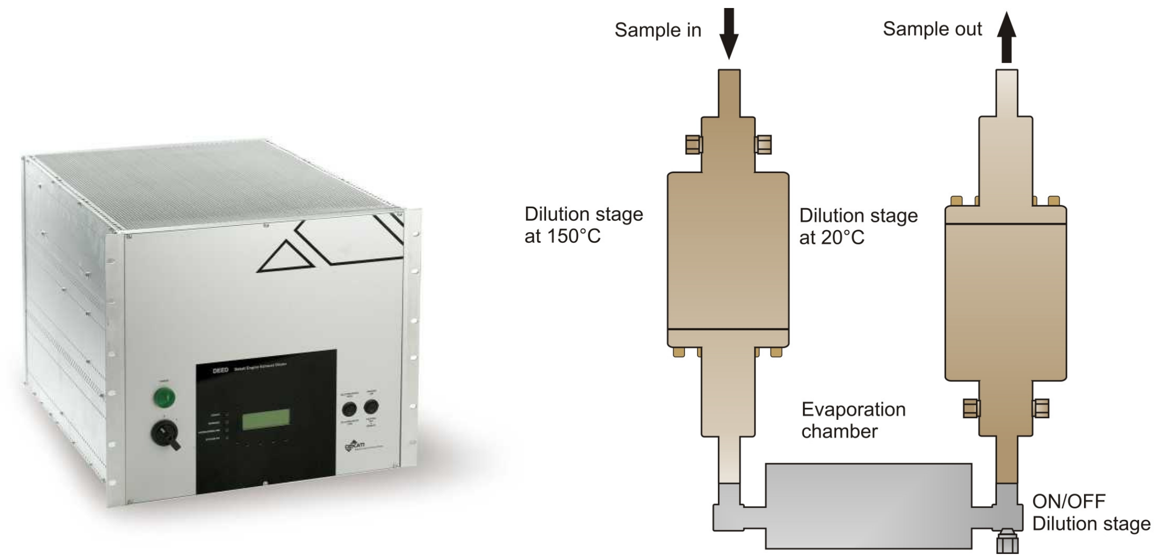

Figure 3. DEED unit and operating principle of the Dekati® Engine Exhaust Diluter, DEED.

The DEED can be used for direct tailpipe sampling by using the DEED-150 POST-DPF sampler and DEED-300 PRE-DPF sampler. The DEED-150 consists of a perforated probe and a heated sampling that can be controlled by the DEED unit. The DEED-300 pre-dpf sampler enables connecting the DEED system to pre-dpf conditions where typically particle concentration, temperature and pressure are high. The DEED-300 increases the total dilution ratio of the DEED system by two additional dilution stages. The DEED-300 uses a small orifice to sample exhaust from pre-dpf conditions. A part of the sample is lead to a mini-CVS axial diluter while the excess raw exhaust is lead to a local exhaust. The sampling probe is heated with automatic heater control from the DEED system. The sample is drawn from the mini-CVS to the Dekati® ejector diluter where it is further diluted and then led into the DEED system.

Dekati® Fine Particle Sampler

Dekati® Fine Particle Sampler (FPS-4000) is a versatile sample-conditioning unit for emission monitoring and combustion studies. In FPS the dilution is also carried out in two phases and it can be made in different temperatures, with variable dilution ratio, and sample residence time. Each of these parameters is controlled with the FPS software.

The first stage dilution is carried out in a perforated type diluter to minimise particle losses, second stage dilution is made in an ejector type diluter. By changing the first stage dilution temperature, and dilution ratio the system can be used e.g. to maximise or minimise nucleation of volatile compounds and sulphur compounds in the exhaust. More detailed technical specifications can be found e.g. in the FPS brochure and user manual.

The combination of ELPI™ and FPS enables fast and efficient studies of sample conditioning effects on combustion particle concentration and size distribution. The FPS can be connected into the ELPI™ inlet, dilution parameters can be changed with the FPS software and the changes can be detected with ELPI™ in real-time.

When sampling directly from the tailpipe (Figure 4) the FPS is connected directly into the hot tailpipe. The first stage diluter can be heated with a probe heater (DH-1411 (110V, DH-1423 (230V)) and the dilution air with the pressurised air heater (DH-1711 (110V), DH-1723 (230V).

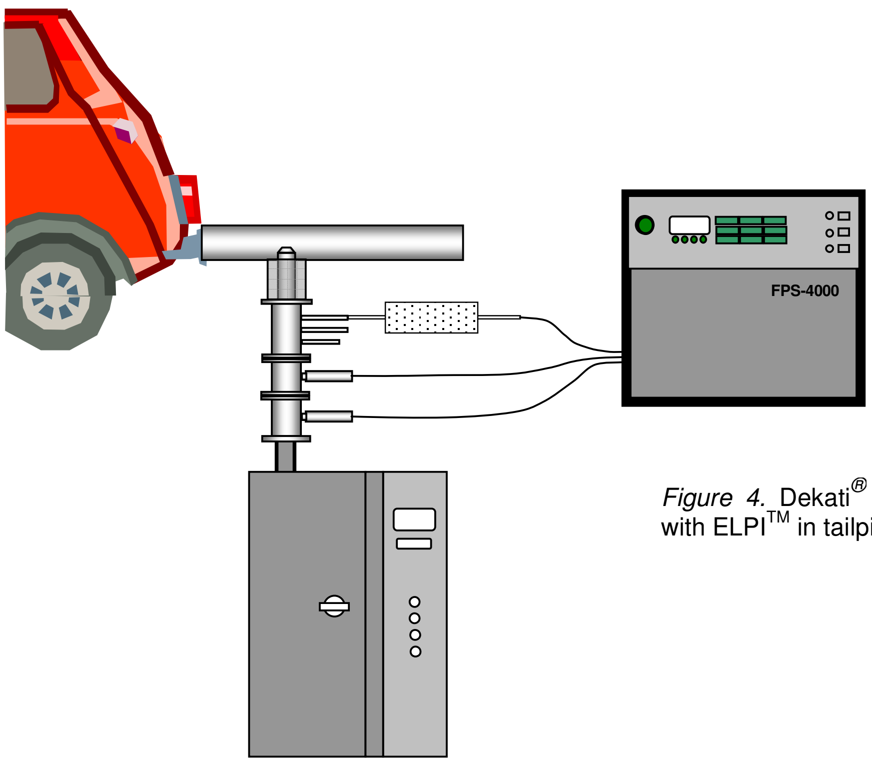

Figure 4. Dekati® Fine Particle Sampler with ELPI™ in tailpipe measurements.

Sampling from CVS

If a CVS tunnel is used for sample dilution the sample can be taken directly out of the CVS into ELPI™. If extra dilution is needed, the sample can first be taken from the CVS into either one Dekati® ejector diluter, DEED or Fine Particle Sampler, and then to ELPI™ as presented in Figure 5.

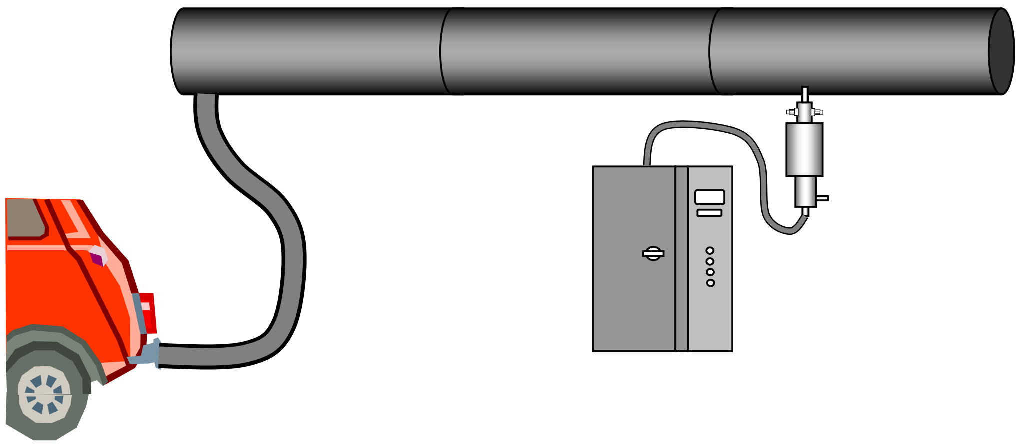

Figure 5. Sampling from a CVS tunnel through Dekati® diluter into ELPI™.

Thermodenuder

Dekati® Thermodenuder (ELA-111 (110V), ELA-230 (230V)) is used to remove volatile compounds out of the sample particle stream. The volatile compounds may form new particles by nucleation, or grow existing particles by condensation. Thermodenuder is used to prevent these effects so that only soot particles are measured.

The effect of sampling conditions on the measured particle size distribution may be significant especially when measuring from conditions where the concentrations of the volatile organic compounds are high. In vehicle exhaust the two major particle modes are nucleation mode and soot mode. The nucleation mode is very sensitive to sampling conditions and can in some cases overwhelm the accumulation mode when looking at the number concentration data (Figure 6).

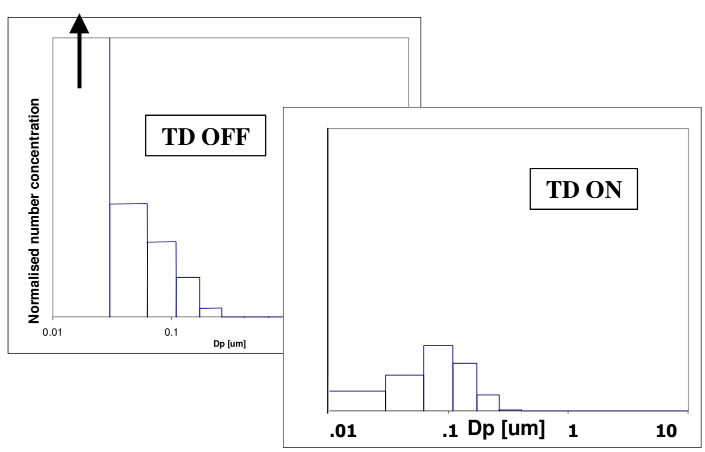

Figure 6. Effect of the Dekati® Thermodenuder on particle size distribution measured with ELPI™.

In the Dekati® Thermodenuder the sample is first heated up to 250 °C where most of the hydrocarbons in the sample volatilise. After the heating the sample is lead through an adsorber where the sample is cooled and the hydrocarbons adsorbed into active charcoal. The Dekati® Thermodenuder has been designed for flow rate of 10-20 lpm so that it can easily be connected into the ELPI™. More information on the Dekati® Thermodenuder can be found in Dekati Ltd Technical note: Sampling automotive exhaust with Thermodenuder.

ELPI™ Publications

Examples of the use of ELPI™ in automotive exhaust measurement are found in numerous publications. Below are few examples. More complete list of ELPI™ related publication is available at www.dekati.com

Diesel emissions

Ahlvik, P., Ntziachristos, L.,Keskinen, J. and Virtanen, A. (1998) Real Time Measurements of Diesel Particle Size Distributions with an Electrical Low Pressure Impactor, SAE Technical paper series 980410.

Virtanen, A., Ristimäki, J., Marjamäki, M., Vaaraslahti, K., Keskinen, J. & Lappi, M. 2002. Effective Density of Diesel Exhaust Particles as a Function of Size. SAE Technical Paper Series 2002-01-0056.

Maricq, M., Podsiadlik, D., Chase,R. (2000). Size Distributions of Motor Vechile Exhaust PM: A Comparison Between ELPI and SMPS Measurements. Aerosol Science and Technology 33: pp. 239-260.

Witze, P.O., Chase, R.E., Maricq, M.M., Podsiadlik, D.H. & Xu, N. 2004. Time.Resolved Measurements of Exhaust PM for FTP-75: Comparison of LII, ELPI , and TEOM Techniques. SAE Technical Paper Series 2004-01-0964.

Maricq, M., Xu, N. & Chase, R.E. 2006 Measuring Particulate Mass Emissions with the Electrical Low Pressure Impactor. Aerosol Science & Technology. Vol 40, pp. 68 – 79.

Gasoline emissions

Maricq, M., Podsiadlik, D. and Chase, R. (1999) Examination of the Size-Resolved and Transient Nature of Motor Vehicle Particle Emissions, Environ. Sci. Technol. 1999, 33, 1618-1626.

Maricq, M., Podsiadlik, D. and Chase, R. (1999) Gasoline Vehicle Particle Size Distributions: Comparison of Steady State, FTP, and US06 Measurements, Environ. Sci. Technol. 1999, 33, 2007-2015.

Mohr, M., Forss, A.-M. and Steffen, D. (2000) Particulate Emissions of Gasoline Vehicles and Influence of the Sampling Procedure. SAE Technical paper series 2000-01-1137.

References

Marjamäki, M., Ntziachristos, L., Virtanen, A., Ristimäki, J. Keskinen, J., Moisio, M., Palonen, M. & Lappi, M. 2002. Electrical Filter Stage for the ELPI. SAE Technical Paper series 2002-01-0055

Dekati Ltd. 2003. Technical note. Substrates and filters for Dekati® Impactors.

Dekati Ltd. 2004. Technical Note. Sintered collection plates.

Dekati Ltd. 2002. Technical Note. Dekati® ejector diluter in exhaust measurements.

Dekati Ltd. 2004. User Manual. Dekati® diluter.

Dekati Ltd. 2003. Technical Note. Sampling automotive Exhaust with a Thermodenuder.

Dekati Ltd. 2005. FPS User manual.

Mikkanen, P., Moisio, M., Keskinen, J., Ristimäki, J., Marjamäki, M. (2001). Sampling Method for Particle Measurements of Vehicle Exhaust, SAE Technical paper series 2001-01-0219

Dekati Ltd. 2005. ELPI User manual.

For more detailed set-ups for specific applications, please contact Dekati Ltd at support@dekati.fi